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(54) A SYSTEM FOR THE CONVERSION OF SEA WAVE ENERGY

(71) We, KJELL BUDAL, of Planetveien 33 B, 7000 Trondheim, Norway, and JOHANNES FALNES, of Dalhaugveien 52, 7000 Trondheim, Norway, both Norwegian subjects, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a system adapted to convert the energy of sea waves into an alternative form of usable energy. The system is to be positioned wholly or in part in the sea, and comprises at least one movable member which is made of a solid or elastic material, and which under the influence of the sea waves is capable of performing oscillations. The movable part of parts is or are associated with at least one damping resistance capable of producing usable energy and/or dissipate energy.

The main purpose of the system is to generate energy, but it may also wholly or in part be used as a breakwater.

Various systems have been envisaged for the utilization of the energy of sea waves, but such systems have only been capable of providing rather small quantities of energy for particular purposes, such as for the operation of bilge pumps or signal buoys at sea. However, in recent times concrete suggestions have been made relating to big scale energy production. Reference may here be made to papers in the periodicals Nature, *249*, pp 720—724 (1974) and IEEE Ocean, 1, 240—243 (1974). Such suggestions refer to big mechanical oscillating systems comprising movable structural members made of concrete or other solid building materials, adapted to make the waves interact with the oscillating system through such movable members. The movable members are to operate pumps which, in turn, are to operate a turbine coupled to an electric generator.

The U.S. Patent Specification No. 2,886,951 discloses a hydraulic resonator, wherein a liquid mass in a tube or chamber directly interacting with the sea is forced to move by the waves. The oscillating liquid mass may be utilized for the generation of energy, for instance thereby that the liquid, when in its top position, is partly drained into a basin situated above the ocean level and that liquid from that basin is fed through a turbine back into the sea.

The natural frequency of a mechanical oscillating system is

$$(1/2\pi)\sqrt{S/M},$$

where S is the spring or elasticity constant of the system and m is the total effective mass. In envisaged wave power absorbers S is mainly due to buoyancy or other gravity effects. The total mass includes the hydrodynamic added mass and, possible, also the transformed tuning mass, which is to be discussed later.

It is well known that the displacement of an oscillating system has the highest value when the natural frequency of the oscillating system is equal to the frequency of the existing force. It is known to utilize this effect in the conversion of ocean wave energy by means of liquid masses tuned to resonance, see for instance the hydraulic resonator disclosed in the U.S. Specification No. 2,886,951, but it is not hitherto known to use resonance tuning for the purposes of conversion of sea wave energy in mechanical systems comprising movable members which are caused to oscillate by the waves.

Known mechanical systems would have a natural frequency which is substantially higher that the frequency range which is typical for the ocean waves, and they do not comprise means adapted to adjust the natural frequency in accordance with variations in the wave frequency.

Hydraulic oscillation systems tuned to resonance have certain disadvantages if applied to generation of usable energy. Primarily, the loss due to liquid friction is rather substantial. Further the oscillating system must be of considerable physical

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dimensions, and finally, the tuning of the frequency of such a system within a full octave is problematic, but desirable for the absorbtion of the energy of actual waves in most ocean areas.

According to the present invention we provide an apparatus for the conversion of sea wave energy comprising a movable member a so-called interacting member, which is made of solid or elastic material and which is an integral part of a damped oscillating system which comprises an energy absorbing mechanism which is adapted to produce usable energy and/or dissipate energy, and wherein the said interacting member interacts with the waves and thereby is subjected to oscillating forces from the waves so as to make the oscillating system oscillate, wherein a flywheel is so coupled to the interacting member, as to add to the effective mass of the total oscillating system to the effect that the natural frequency of the system is made essentially equal to the characteristic frequency of the sea waves.

According to another aspect of the present invention we provide an apparatus for the conversion of sea wave energy, of the type which comprises at least one movable member, a so-called interacting member, which is made of solid or elastic material and which is an integral part of a damped oscillator system which comprises one energy absorbing mechanism which is adapted to produce usable energy and/or dissipate energy, and wherein the said interacting member is interacting with the waves and thereby subjected to oscillating forces from the waves so as to make the oscillating system oscillate, wherein a drive means is provided and adapted to impart an oscillating movement to the interacting member of a variation in amplitude and frequency corresponding to that of the exciting wave force so as to optimize the net energy conversion in the system.

In the performance of the invention, the part of the structure which is subjected to the wave forces and thereby caused to oscillate, a part which is hereinafter referred to as the interacting member, is coupled to one or a number of masses, hereinafter referred to as the tuning mass, which may be arranged within the structure, in the sea, on the sea bottom or ashore, and which is essentially not subjected to direct influence of the wave forces, but oscillate in step with the interacting member so that the effective mass of the total oscillation system is of a sufficient value to cause the natural frequency of the system to be equal to or approximately equal to the characteristic wave frequency. Preferably, the tuning mass should oscillate at a much greater velocity than the interacting member, as thereby the tuning mass required would be relatively small, so that the total system would not be too volumenous. A small mass also provides the advantage that it is more easily varied in size and/or force than a big mass, to the effect that the natural frequency of the system may be more easily adjusted. Further, the conversion of the kinetic energy of the mass into an another energy form, such as usable energy, is technologically more easily performed when using a rapidly oscillating mass than by using a slowly oscillating mass.

The functioning of the resonant-tuned system described above may be explained in the following way: The incoming waves cause the system to move, whereby an outgoing wave is generated. If the oscillation system is small compared to the wavelength or if it is circular symmetric, this wave is annular. This outgoing wave is superposed on the incoming wave in such a manner that the resultant wave which passes the system, is of a reduced amplitude and consequently of a reduced energy. Consequently the system must have absorbed energy from the wave. Evidently the capacity of the outgoing wave to wipe out the incoming wave is greater when the time variation or frequencies of the outgoing wave is similar to that of the incoming wave. However, a linear oscillation system may reproduce the time variation of the incoming wave, only in one case, viz when the incoming wave is purely sinusoidal. Ocean waves are never sinusoidal, to the effect that the outgoing wave only approximately is similar to the incoming wave, and the deviation is greater the more the incoming wave differs from being sinusoidal. The conclusion is that a free, resonance-tuned, suitable damped oscillating system is a very effective wave absorber in sinusoidal ocean waves, but less effective in ordinary wind generated waves.

In the latter case an improvement of the absorbing system is as follows. Presume that the flywheel is influenced by a controllable motor or other controllable member, then the flywheel, and thereby the interacting member can move in a more controlled manner. Alternatively, the fly wheel may be replaced by a combined motor and generator which controls the movement of the interacting member. Presume that the interacting member be forced by the motor-and-generator to move in such a fashion that it generates outgoing waves of the same time variation as the incoming waves, but of opposite phase. Evidently such a system functions as a very effective wave absorber in all kinds of waves, since the system is able to generate and, hence, wipe out waves of arbitrary

time variation. This energy absorption manifests itself in the fact that the generator delivers more energy than the motor uses. The difference corresponds to the usable energy.

A combination of the features of the invention defined above is also within the scope of the present invention.

Further detailed features of the invention will appear from the following description of a number of embodiments of the system, illustrated in the accompanying drawings, and from the claims.

In the accompanying drawings;

Figures 1 to 6 illustrate examples of how the system of the invention may be reduced in practice.

In all figures, identical reference numerals are used in connection with parts which correspond to each other.

In Figure 1, is a tank which is semi-submerged in an equiliposition in the sea. The tank 1 is kept in this position by a wire, chain or the like 2, which is passed over rollers 3 and 4 mounted in casing 5 secured to the sea bottom and on to a buoyant member 6. Due to the buoyancy of the member 6; the wire 2 is constantly subjected to a tensile force. The roller 3 is associated with a fly wheel 7 which is again associated with an electric generator in any convenient manner, wherefore the generator and its mechanical and electrical connections are not indicated in the drawing. Thus, the fly wheel and the generator are integral parts of the system.

When the tank 1 is subjected to sea waves, it is caused to perform reciprocating, vertical movement (oscillations) to the effect that the roller 3 and its fly wheel 7 with the generator is caused to perform oscillating rotational movements. By suitably arranging the parameters of the system, such as the movement of inertia of the fly wheel 7, the diameter of the roller 3 engaging the wire 2, the oscillating system may be made to have a natural frequency close to the characteristic frequency of the waves. Preferably the peripheral velocity of the fly wheel 7 should be by far greater than the linear velocity of the tank whereby the mass of the fly wheel may be relatively small. The electric generator, which supplies the usable energy, preferably is driven by the periphery of the fly wheel 7.

When the characteristic frequency of the waves varies, the natural frequency of the oscillating system should also be varied. This may be effected by a variation of the tuning mass. A fly wheel is particularly suited for this purpose, as the moment of inertia of the same is easily adjustable, e.g. by radially displacing masses mounted on the fly wheel. Alternatively, the effective mass may be adjusted by an adjustment, such as by a suitable gear, of the relation between the linear movement of the wire 2 and the rotational movement of the fly wheel.

As mentioned above, the fly wheel may also be subjected to a force from a controllable or adjustable motor, in addition to the other forces influencing the system, such as its moment of inertia, elasticity forces, (e.g. due to buoyancy) damping forces and the forces supplied by the waves, to the effect that the tank, the interacting member, may perform a movement which is fully in step with the incoming waves. Possibly, the fly wheel may be replaced by an electrical motor-generator, or a hydraulic turbine or pump, controlling or adjusting the tank movements.

Figure 2 illustrates a variant of the system shown in Figure 1 in which the roller-fly wheel combination 3—7 is duplicated and arranged in the tank 1. Consequently, the wire 2 and the roller 4 are also duplicated, as shown, the rollers 4 being as before, mounted at the sea bottom.

Figure 3 illustrates a system in which the rollers are in the form of toothed wheels meshing with tooth rods 8 provided on a buoyant member 9 anchored to the sea bottom through wires 10. When the tank 1 is oscillating, the toothed rollers 3 roll along the rods 8, thereby rotating the fly wheels 7.

Figure 4 illustrates a system similar to that of Figure 3 but having the buoyant member 9 replaced by a frame structure 1 mounted on the sea bottom.

In the embodiments shown in the Figures 1 to 4, the transmission means between the interacting member and the remainder of the oscillating system, have been mechanical, such as by wires, tooth gears. Otherwise, hydraulic transmission means are possible.

The above-mentioned embodiments are semi-submerged.

The Figures 5 and 6 illustrate the use of totally submerged wave-interacting oscillating systems.

Figure 5 illustrates a submerged system according to the invention, comprising a pair of gas filled tanks 12 and 13, respectively, interconnected through a conduit 14. The tank 12 is provided with a movable or flexible wall portion 15, which is the interacting member and is positioned below the sea surface. The tank 13 is provided with rigid walls and may be positioned ashore or submerged, possibly on the sea bottom. The conduit 14 is provided with a turbine 16 associated with a generator, as described above.

The movements of the tank 12 under the influence of the waves, cause the wall

portion 15 to oscillator, thereby varying the volume of the tank 12, to the effect that gas is flowing through the conduit 14 with the turbine 16 which is caused to rotate. As in the embodiment shown in Figure 2 and described above, the tuning of the system may be effected by making the turbine in the form of a motor-pump unit provided with a fly wheel.

Alternatively the tank 12, the conduit 14 and the lower part of the tank 13 may be filled with a liquid such as water or oil. Then the turbine 16 may be a water turbine or another hydraulic machine. The remaining upper part of tank 13 is still filled with gas, the volume of which fluctuates in accordance with the movement of the flexible wall 15.

Figure 6 illustrates a variant of the system shown in Figure 5, wherein each of the containers 12 and 13 is provided with a flexible wall portion 15. The two containers are arranged at a distance of about the half of the wave length. Consequently, waves coming in in the direction of length of the conduit 14, will set up pressures of opposite phases in the two containers, thereby causing an increased flow of liquid or gas through the turbine 16 mounted in the conduit 14.

WHAT WE CLAIM IS:—

1. Apparatus for the conversion of sea wave energy comprising a movable member a so-called interacting member, which is made of solid or elastic material and which is an integral part of a damped oscillating system which comprises an energy absorbing mechanism which is adapted to produce usable energy and/or dissipate energy, and wherein the said interacting member interacts with the waves and thereby is subjected to oscillating forces from the waves so as to make the oscillating system oscillate, wherein a flywheel is so coupled to the interacting member, as to add to the effective mass of the total oscillating system to the effect that the natural frequency of the system is made essentially equal to the characteristic frequency of the sea waves.

2. Apparatus for the conversion of sea wave energy, of the type which comprises at least one movable member, a so-called interacting member, which is made of solid or elastic material and which is an integral part of a damped oscillator system which comprises one energy absorbing mechanism which is adapted to produce usable energy and/or dissipate energy, and wherein the said interacting member is interacting with the waves and thereby subjected to oscillating forces from the waves so as to make the oscillating system oscillate, wherein a drive means is provided and adapted to impart an oscillating movement to the interacting member of a variation in amplitude and frequency corresponding to that of the exciting wave force so as to optimize the net energy conversion in the system.

3. Apparatus as claimed in Claim 2, further including at least one flywheel means associated with said interacting member so as to add to the effective mass of the total oscillating system to the effect that the natural frequency of the system is made essentially equal to the characteristic frequency of the sea waves.

4. An apparatus according to any preceding Claim wherein said interacting member is a floating tank adapted to perform vertical reciprocating movements in the sea.

5. An apparatus according to Claim 4 wherein said movements of said tank are transmitted to turn a generator for producing electrical energy.

6. An apparatus according to Claim 5, wherein said generator is housed at a fixed position externally of said tank and the movements of said tank are transmitted to said generator through a wire or cable maintained under tension which passes over a roller to which the generator is connected.

7. An apparatus according to Claim 5 wherein said generator is housed within said tank and is connected to rollers mounted on said tank, said rollers being connected to a substantially stationary member whereby said rollers rotate as said tank oscillates.

8. An apparatus according to any of Claims 1 to 3 wherein two fluid filled tanks are interconnected by a conduit, said interconnecting member comprising a flexible wall portion arranged in at least one of said tanks and adapted to oscillate at the frequency of the sea waves and to act on said fluid, whereby said fluid oscillates between said tanks through said conduit, and a turbine within said conduit which is operated by said oscillating fluid.

9. An apparatus according to Claim 8 comprising one flexible wall member on one tank, said one tank, conduit and a portion of said other tank being filled with liquid and the remaining portion of said other tank being filled with gas.

10. An apparatus according to Claim 8 comprising one flexible wall member on one tank, said tanks and conduit being filled with gas or liquid.

11. An apparatus according to Claim 8 comprising a flexible wall member on each tank, said tanks and conduit being filled with liquid or gas and being spaced apart at

a distance of half the characteristic wavelength of the sea waves.

12. Apparatus for the conversion of sea wave energy substantially as described with reference to and as shown in any of the accompanying drawings.

For the Applicants,
CARPMAELS & RANSFORD,
Chartered Patent Agents,
43, Bloomsbury Square,
London, WC1A 2RA.

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Fig. 1.

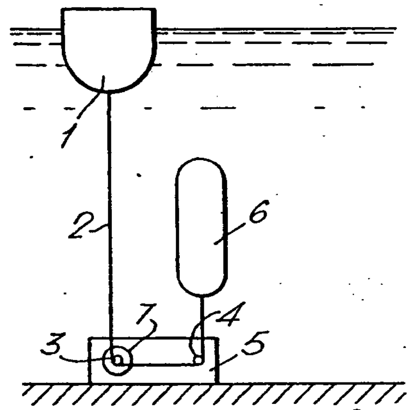


Fig. 2.

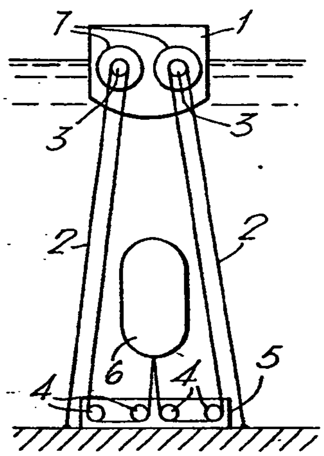
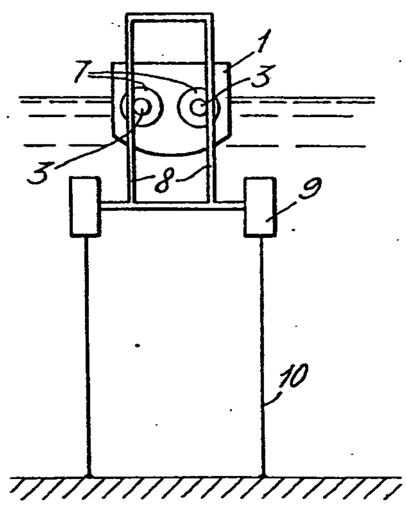


Fig. 3.



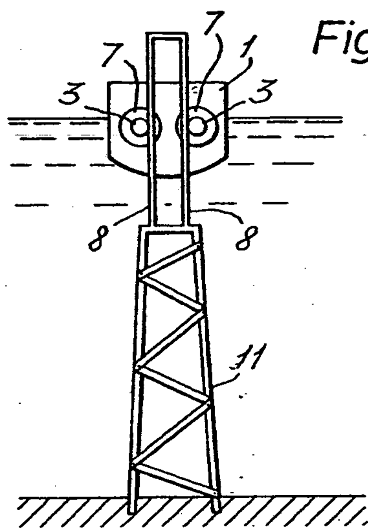


Fig.4.

Fig.5.

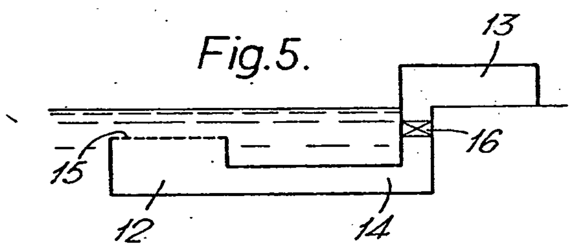


Fig.6.